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THE SOLAR PROPAGATING FRAME FOR ROOTING CITRUS AND OTHER SUBTROPICAL PLANTS

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VEGETATIVE PROPAGATION

The propagation of plants by the use of cuttings is one of the oldest methods known. While almost the only method used with some important groups of plants, it is little used with others, partly because of the difficulties encountered as compared with producing new plants from seed. Many plants commonly supposed not to root from cuttings are readily propagated in this way if the right kind of cuttings are selected and given the right treatment. Recently more attention has been given to vegetative propagation, particularly of fruit-tree stocks, in order to eliminate the variability so apparent in a lot of unselected seedlings. Aside from the commercial advantage of uniform stocks it is highly important in certain types of investigational work, particularly with fruit varieties, that great uniformity in the stock be secured to make the results of the experiments trustworthy.

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In the citrus group there is still another reason for resort to vegetative propagation. As pointed out in a recent paper [1] there are a number of the recently created citrus hybrids that possess special merit as stocks but which are few seeded or even almost seedless. Some of these hybrids come true from seed, such as the Rusk citrange and Thomasville citrangequat, while others, like the Eustis limequat, do not. Even in the case of hybrids like the Rusk citrange which propagate uniformly and without noticeable variation from seed (the unfertilized embryos of the seed being in effect buds from the mother tissue), there is a period when the small seedlings grow very slowly, and they may easily be stunted through improper care.

Not only do rooted cuttings insure uniformity of type and vigor, but where the improved methods recently developed are used practically a year's time can be saved in growing stocks to budding size, an advantage certainly sufficient to offset the additional trouble and expense of providing special equipment. Until recently it was deemed necessary for the best results that the rooting work should be carried on in a well-equipped greenhouse using steam coils to supply bottom heat. Fairly good results, however, had been obtained under favorable conditions by using a frame in which a deep bed of manure supplied bottom heat during the initial period, but this method could not be relied upon always, and the period required for rooting was greatly lengthened.

SELECTION OF CUTTINGS AND METHODS OF HANDLING

The main point of difference between the usual methods and those devised by the writers is in the type of twig selected for the cutting. Instead of taking well-matured rounded wood of pencil size or larger with foliage removed (as usually advised in standard treatises), only slender twigs with leaves attached (medium soft wood cuttings) are employed. Frequently the terminal shoots are taken, though when these shoots are long enough they may be cut up into two or more cuttings 5 to 6 inches long. Such slender twigs should have reached a stage of sufficient maturity so that they are not soft, but they need not have become rounded and hard. (See fig. 3.) The cuttings should be so handled that no wilting takes place between the time of removal and placing in the rooting bed. In the case of taking cuttings in the field, they should be clipped directly into a wet sack.

No leaves should be removed except one or two at the base of the cutting. Each cutting should be reclipped just below a node with a sharp thin-bladed knife immediately before inserting it in the rooting bed. In a greenhouse or elsewhere the humidity must be maintained at a high point to prevent wilting at any time. This also entails close attention to ventilation and requires frequent applications of water in the form of a fine spray. The rooting medium should be fairly coarse sharp sand that will not readily pack, thereby preventing good aeration. A mixture of fibrous material, such as clean coconut fiber, with the sand gives good results, but ordinary leaf mold should not be used unless the whole mixture is first steril-

[1] Swingle, Walter T., and T. Ralph Robinson. Two important new types of citrus hybrids for the home garden—citrangequats and limequats. *In* Jour. Agr. Research, v. 23, p. 229–238, 5 pl. 1923.

ized by steam heat. If the sand or any prepared mixture is to be repeatedly used it should be sterilized occasionally.

The rooting bed should be at least 6 inches in depth, preferably 8 inches, and the cuttings should be inserted to a depth of about 4 inches. They should be given fairly heavy shading at first, gradually allowing more illumination as they give evidence of having become established.

In a greenhouse where the temperature can be controlled through the use of steam coils the best results are obtained with most citrus varieties, hybrids, and citrus relatives by maintaining a soil temperature of 80° to 90° F., with the air temperature somewhat cooler, 70° to 80° F. Given such temperature conditions with the atmospheric humidity kept constantly high enough to prevent wilting, the tender growing shoot inserted in the rooting bed seems hardly to stop growing, at least only for the two or three weeks necessary for the formation of roots. Usually within a month to six weeks most of the cuttings are ready to be potted and in a year's time can be grown to a size suitable for budding. Seedlings under similar conditions will usually require two years or more from the time of planting seed. This is because the seedlings soon exhaust the scanty supply of food stored up in the seed, and the few small leaves that have been formed elaborate only very slowly the starchy food indispensable for new growth. A cutting, on the other hand, with several full-sized leaves attached is able to produce by active photosynthesis carbohydrate plant food in abundance, thus permitting the rapid growth of roots and new leaves.

The lack of greenhouse equipment and the expense of providing such equipment have seemed serious objections to any widespread use of these methods, notwithstanding the saving of time and the uniformity secured by vegetative propagation. The use of steam heat has also made it necessary to do most of the rooting work in the cooler months of the year, largely necessitating almost complete suspension of this work in summer.

FRAME EXPERIMENTS

To obviate this difficulty some experiments were made with frames deriving bottom heat from a deep bed of manure. Small experimental hotbeds for rooting citrus cuttings were constructed during 1922 at Washington, D. C., at Eustis, Fla., and at Lake Alfred, Fla., at the last-named place in cooperation with the Florida Agricultural Experiment Station at the Citrus Experiment Station. The results obtained, while encouraging, were not entirely satisfactory except for a few varieties which root very easily, such as the rough lemon, lime, and citron.

SUNLIGHT FOR BOTTOM HEAT

During the spring of 1923 one of the writers (Mr. Robinson) observed a rooting frame in use at Buena Vista, Fla., built by Charles H. Steffani, a propagator connected with the Plant Introduction Garden of the United States Department of Agriculture. This frame, of simple construction, made use of sunlight to furnish bottom heat and was being used successfully for rooting the softwood cuttings usually handled in greenhouses.

A somewhat similar contrivance was apparently first illustrated and described in the report of the Hawaii Agricultural Experiment Station for 1920.[2] J. E. Higgins, at that time horticulturist at the station, appears to have been responsible for its introduction there. The original solar propagating frame (for such the Hawaiian contrivance seems to be) is described as follows:

This device consists essentially of a box, the major part of which is covered with a closely hinged glass cover. The remaining part of the box is covered with a 1 by 12 inch board through which holes are cut to admit the pots. These are dropped into the box as far as the rim. The bottom of the box may be zinc lined and filled with water to a depth of several inches, or it may be filled with black-painted bottles full of water. The sun's rays upon the water or upon the black-painted bottles through the glass cover generate a large amount of heat, which is retained by the water at an approximately uniform temperature throughout the night. The hinged top may be closed or opened slightly, according to the needs. The cuttings are placed in sand or other

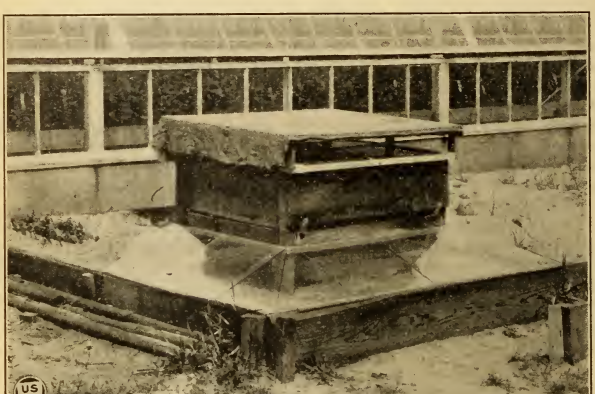

FIG. 1.—View of the solar propagating frame. Photographed from the southeast

material in the pots, the bottoms of which are filled with broken rock or pottery to provide drainage. A frame, which is partly covered with cheesecloth, provides shade for the cuttings. Openings at the end permit free passage of the air and prevent the accumulation of heat in the upper part of the propagation box, where it is not desired.

The frame observed at Buena Vista differed in several important particulars from the one just described, providing greater capacity and at the same time being of simpler construction. The rooting bed of sand was raised about a foot above the ground, and sunlight was allowed to heat the inclosed space under this bed through two glass sashes sloping to the east and west from the bottom of the rooting frame to a point close to the ground. An important feature was the use of ¼-inch mesh wire forming the bottom of the rooting bed. Cement spread thinly over this screen wire prevented the sand from

[2] Westgate, J. M. A device for securing bottom heat in the propagation of cuttings. *In* Rpt. Hawaii Agr. Exp. Sta., 1920, pp. 25–26, fig. 1. 1921.

sifting through but provided numerous small openings for drainage and aeration.

The rooting bed proper was covered by hinged sash. About 6-inches above the sash was placed a burlap canopy to furnish shade and moderate the heat. Pans of water were placed on the ground under the side sashes to maintain the humidity and in some degree equalize the temperature, retaining much of the absorbed heat during the night.

This form of solar propagating frame seemed to offer distinct promise for use with citrus cuttings, and accordingly in June, 1923, one was constructed along similar lines for a preliminary experiment at Washington, D. C. Figures 1 and 2 will give an idea how this frame was constructed. In this preliminary test only the simplest sort of a rooting frame was put together, with the purpose of demonstrating, if possible, that the device could be utilized at little

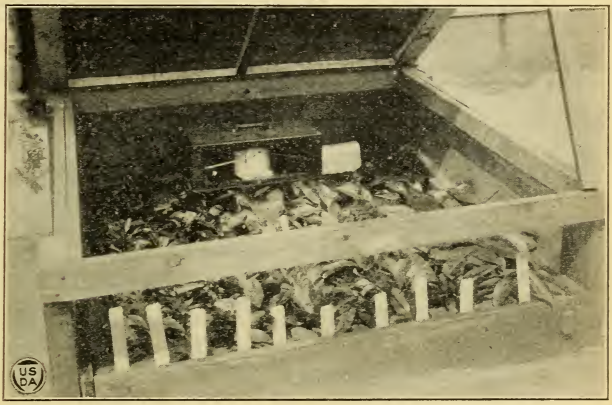

FIG. 2.—Near view of plants in the solar propagating frame with front board removed; recording thermometer in background

expense by anyone having only fair ability in handling tools and some experience in propagation technique. Glass was provided on all four sides of the raised rooting frame, but this feature is not essential provided the glass area is sufficient. The glass surface for collecting heat should be, roughly, two or three times the area of the rooting frame.

The wire bottom of the rooting frame was covered with moss (instead of cement), permitting perfect drainage, aeration, and penetration of the absorbed heat from below.

The first rooting frame used was a small one, 30 by 36 inches, raised 12 inches above the ground, in this case a bed of clean sand. A hinged sash was placed on top of this frame, and a light framework supported a burlap canopy 4 inches above the sash.

The glass base extended 18 inches on all four sides (see fig. 1), sloping from the base of the rooting bed. A shallow pan of water was placed under the rooting frame to maintain an even degree of humidity.

ROOTING TEST WITH CITRUS

On June 28, 1923, 188 cuttings (chiefly citrus) were placed in the rooting bed. The following extract from the greenhouse report (made by Mr. May) covering this experiment will indicate what results may be expected with average summer weather in the latitude of Washington.

These cuttings were put in on June 28 and were all taken up on July 30 (32 days) to note results. For the first 10 days these cuttings were sprayed two or three times daily; from then on until they were taken out they were watered only when the condition of the cuttings and the sand (ordinary river sand) seemed to require it.

No ventilation was given these cuttings except on the last four days before they were taken out. It should be remembered that this case was not air-tight, and there was always some ventilation through the cracks of the rough material of which it was constructed. These cracks seemed to furnish just about the right amount of ventilation to prevent these cuttings from becoming weak, as they probably would in a regular "sweat box." They also at no time showed any signs of wilting, although they were carrying considerable foliage, especially the lychee cuttings.

TABLE 1.—*Results obtained by using a solar propagating frame for rooting citrus cuttings tested at Washington, D. C., June 28 to July 30, 1923*

C. P. B. No.	Variety	Number of cuttings				Remarks
		Rooted	Callused	Not callused	Dead	
7775–E	Microcitrus sp.	1	9	10	0	Condition good.
11338	Cleopatra mandarin	7	8		0	47 per cent rooted.
48010–M	Citrangequat	12	8		0	60 per cent rooted.
11540–AE	Rusk citrange	20			0	100 per cent rooted.
11893	Cuban shaddock	20			0	Do.
11178	Citrus medica	20			0	Do.
11298	Kansu orange	18	2		0	90 per cent rooted.
11630	Sour orange	20			0	100 per cent rooted.
1158	Sweet lemon	20			0	Do.
11643	Lychee		2	8	0	Still green and healthy.
12037	Avocado		2	1	0	Do.
	Total	138	31	19	0	

It will be noted that five lots of citrus cuttings gave 100 per cent of successful results. Not merely had they formed roots, but the roots were numerous, healthy, and in fact the plants were established. In only one lot of citrus (Microcitrus, No. 7775–E) was the showing poor in the time allowed, and this species is one very slow to start roots. With the Cleopatra mandarin (No. 11338) and citrangequat (No. 48010–M), those not already rooted were nicely calloused, indicating that with additional time most of them would strike roots. As a matter of fact, all these plants were replaced after examination, and when taken out on August 30 all but one of the citrangequats were rooted; two more Cleopatras and seven Microcitrus cuttings had rooted.

Figure 3 shows the character and extent of the root systems developed in 32 days, starting with small terminal twigs with leaves attached. Such plants need no careful hardening process, but are ready for plotting or even lining out in nursery rows with judicious handling thereafter. In removing from the rooting bed, precautions

should be taken to avoid injury to the tender roots. The cuttings should not be left in the bed longer than necessary to form roots 1½ to 3 inches in length. At this stage they will need to be established in a soil affording materials for development.

NONCITRUS CUTTINGS

It will be noted that included in this first test were 10 lychee and 3 avocado cuttings. At the time of the first examination no roots had appeared on any of these cuttings, though the shoots were still green and healthy and a few had callused.

Both of these plants have previously been successfully rooted with steam bottom heat in the greenhouse, which led to testing them in the solar frame. The rooting of the lychee from tip cuttings [3] had already been accomplished by Edward Goucher, of the United States Department of Agriculture, using a method which involves tying

FIG. 3.—Root systems developed in solar propagating frame, June 28 to July 30, 1923; Rooted cuttings, left to right, C. P. B. Nos. 7775–E, *Microcitrus virgata;* 11338, Cleopatra mandarin; 48010–M, Thomasville citrangequat; 11540–AE, Rusk citrange; 11893, Cuban shaddock; 11178, *Citrus medica;* 11298, Kansu orange; 11630, sour orange; and 1158, sweet lemon

the cutting to a stick or plant label and allowing only the end of the cutting to come in contact with the surface of the rooting bed. This practice has been found to be an unnecessary precaution, provided the rooting bed is free from damping-off organisms and proper conditions of temperature and humidity are obtained. In fact, lychee cuttings have been repeatedly rooted in the same rooting bed with citrus cuttings and have given almost as good a percentage of successes as citrus plants, although for the best results the time required is usually longer and the temperature must be kept fairly high (80° to 90° F.). The use of a slightly acid rooting medium, such as sand and leaf mold or peat, is favored for rooting lychee cuttings.

[3] Goucher, Edward. Rooting lychee cuttings by means of a high-temperature and high-humidity process. *In* Groff, George Weidman, The lychee and lungan, Appx. 8, 157–159. 1921.

Galloway, Beverly T. Improved method of propagating the litchi. *In* Jour. Heredity, v. 13, p. 201–206. 1922.

Notwithstanding the more exacting nature of these tender tropical plants (avocado and lychee), the final result was quite encouraging. The cuttings were replaced in the same rooting bed, and when reexamined on August 30, 1923, all the avocado cuttings were nicely rooted and starting growth, and two of the lychees had also formed roots. Seven additional lychee cuttings were calloused. The premature removal of these plants for examination on July 30 was a decided handicap, which may have influenced the results with the lychees.

Figures 4 and 5 illustrate the root system developed from small twig cuttings of a seedling of the Collinson avocado, Figure 4 showing it just as it was taken from the rooting frame.

FIG. 4.—Rooted cutting of avocado from a seedling of the Collinson variety, C. P. B. No. 12037 (about half natural size). Rooting the avocado requires about double the time needed for most citrus varieties tested

In the annual report of the California Avocado Association for 1919 and 1920, p. 16, S. W. Jamieson makes brief reference to some experiments on the rooting of avocados from slips, using ether as a preliminary treatment, but this method does not appear to have been further developed. Generally speaking, the avocado has been classed by propagators as a plant not to be propagated from cuttings.

Cuttings have made very satisfactory growth in pots (fig. 5), though it remains for future trial to determine their suitability for orchard plantings. Since our first success, obtained during the winter of 1922–23 in the geenhouse bed at Washington, a few avocado cuttings were

successfully rooted in a frame, depending on manure for initial bottom heat. This frame experiment was carried out during the winter and spring of 1923 at the Citrus Experiment Station at Lake Alfred, Fla., in cooperation with the Florida Agricultural Experiment Station, at the suggestion of one of the writers (Mr. Robinson), the actual rooting work being done by J. H. Jeffries, in charge of the station. In this experiment the cuttings were first induced to form a callus while attached to the parent tree by girdling

FIG. 5.—Rooted cutting of avocado, C. P. B. No. 12037, a seedling of the Collinson, showing the fine root system developed five months after potting

growing twigs (about one-quarter to one-half inch in diameter) and were then removed to the rooting bed. The callus formed was in some instances notched to induce roots to start when it was found after two weeks that they showed no tendency to "break." Contrary to expectations, no roots started from the calloused portion, whether notched or untouched, but in a few instances a ring of roots was formed, starting just above the callus. The percentage of rooted cuttings obtained in this way was too low to be very promising. In the department's greenhouse work with avocados the

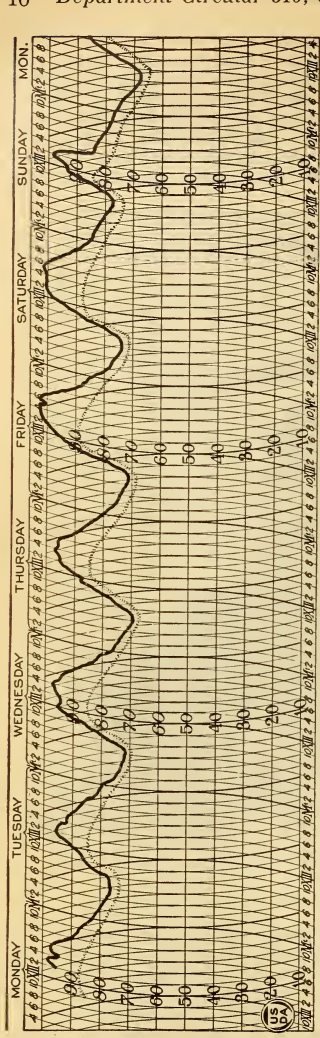

FIG. 6.—Diagram showing air and soil temperatures in the solar propagating frame for the week July 16 to 23, 1923. Air temperature shown by the heavy line; soil temperature by the light line

best results have been secured with rather tender tip cuttings (see fig. 4) cut with a "heel," that is, a small piece of the bark and cambium layer of the branch giving rise to the tip shoot.

As yet no success has been attained in attempts to root the mango from cuttings.

TEMPERATURE RECORDS

It will be noted by referring to Figure 2 that a recording thermometer was placed in the rooting frame, giving an accurate record of conditions during the experiment. This instrument recorded on a single sheet both the air temperature in the frame and soil temperature at a depth of about 4 inches, i. e., about the depth at which the cuttings were inserted.

In addition to these recorded temperatures, a maximum and minimum thermometer was placed on the ground in the shade under the rooting frame. Still another thermometer was laid on the surface of the soil in the rooting frame, partially hidden by the foliage of the cuttings.

The records for four weeks and four days (June 28 to July 30) showed an air maximum of 104° and air minimum of 65° F.; the maximum and minimum for the soil (occurring on the same dates, July 6 and June 30) were, respectively, 93° and 64° F. Figure 6 presents the curves for a typical week in July, the heavy line showing the air temperature in the rooting frame and the light line the soil temperature. The maximum temperature shown by the thermometer

under the rooting frame (in the shade) was 122°, the daily maximum usually exceeding 110° F. whenever there was an average proportion of sunshine.

The thermometer laid on the surface of the rooting bed showed a surprising difference between the temperature of the moist sandy surface and the air temperature recorded on the chart. The surface of the bed was usually from 5 to 10 degrees cooler than the air temperature, doubtless owing to the evaporation going on.

Taking this factor into account it became apparent that while the air temperature recorded on the chart averaged during the daylight hours from 5 to 10 degrees higher than the soil temperature, the actual conditions in the rooting soil were such that the surface was usually slightly cooler than the bottom of the bed, a condition much to be desired. During the night the curves representing the air and soil temperatures gradually approached and finally coincided or nearly so.

It is probable that a certain amount of temperature variation is not harmful and may even be beneficial, provided the range is not too great or the change too sudden. The latitude that can be permitted without detriment will vary considerably even for different species and varieties of closely related plants.

Several consecutive days of cloudy weather without sunshine occurring during the initial test seem to have produced no harmful effect, although a protracted period of such weather would probably be harmful, particularly if accompanied by a relatively low temperature.

STORAGE OF HEAT

After removing the first lot of rooted cuttings (July 30), a second series, including a few other varieties, was immediately started, no change being made in the equipment at this time.

As late August is usually attended with several chilly nights, it was decided at the end of the third week to guard against too violent a drop of temperature at night. As one form of protection pieces of burlap were laid over the glass at night. Further protection was given by placing additional pans of water under the glass exposed to the sun's rays. Three pans of 3-inch depth, about 36 by 16 inches in size, holding about 20 gallons of water, were used. These were painted with lampblack. It was found that the moisture given off by this exposed water surface was too great, saturating the rooting bed in a short time; so covers were placed over them on the second day. Two pans were provided with metal covers painted black and one with clear glass and the temperatures compared under these conditions. As was to have been expected, the water under the glass in full sunlight became somewhat warmer (on the average 4 to 5 degrees Fahrenheit), though the difference between the glass and the metal covers was not great enough to be of critical importance in storing heat for the night hours. As anticipated, a cool spell occurred soon after installing the water pans, with minima for three nights of 56°, 52°, and 53° F., respectively (August 22 to 24).

The heat stored up during the day in the water pans had an evident effect in reducing the drop at night, and the cuttings suffered no apparent check during this chilling period. The soil tempera-

tures recorded were from 6 to 10 degrees higher than the outside air temperature, and the lowest degree of soil temperature reached was only of short duration, just before daylight.

SECOND TEST IN ROOTING CITRUS CUTTINGS

Table 2 presents the result of the second test, using six varieties of citrus.

TABLE 2.—*Results obtained by using a solar propagating frame for roooting six varieties of citrus cuttings tested at Washington, D. C., August 2 to 30, 1923*

C. P. B. No.	Variety	Number of cuttings			Rooted (per cent)
		Calloused	Rooted	Not calloused	
11540-AE	Rusk citrange	4	21		84
48010-T	Thomasville citrangequat	15	6	4	24
1158	Sweet lemon		26		100
11868	Rough lemon		25		100
11338	Cleopatra mandarin	6	7	11	29
11298	Kansu orange	2	23		92
	Total	27	108	15	

As found in the first test, additional time is required to root the citrangequat and the Cleopatra mandarin.

SUGGESTED MODIFICATIONS OF APPARATUS

The Astrophysical Observatory of the Smithsonian Institution demonstrated in 1915 at Mount Wilson, Calif., the practicability of using solar heat for cooking purposes. The apparatus [4] utilized a concave mirror surface rotating with the sun, which focused the sun's rays upon a pipe containing oil, the latter being connected with a tank located in an insulated oven. Temperatures up to 155° C. (311° F.) were obtained in such an oven, and sufficient heat was retained over night (88° to 90° C., or 190° to 194° F., at 6 o'clock a. m.) to continue cooking all night.

Such high temperatures are not necessary in plant-propagation work, though the demonstration mentioned shows the possibility of storing heat by properly designed and insulated reservoirs.

For practical use in plant propagation the cost of the equipment required to utilize solar heat must be kept down to a low figure. Some improvements in the present outfit have been made which, without adding to the cost, will increase the efficiency considerably, particularly with regard to storing heat over night. A double-glazed sash, 6 by 3 feet, placed on the south side of the rooting frame and giving an area about twice that of the latter has been substituted for the glass border surrounding the frame. This makes it possible to examine and handle the cuttings much more readily and would be a necessary arrangement in any commercial model. The double glazing leaving an air space of about 1 inch should prove

[4] Abbot, C. G., F. E. Fowle, and L. B. Aldrich. The great solar cooker on Mount Wilson, Calif. *In* Ann. Astrophys. Observ. Smithsn. Inst., v. 4, p. 311–318. 1922.

effective in cutting off loss of heat by radiation. This is a fairly common design for winter use in northern greenhouses, but would only be necessary in relatively cool weather with a decided drop in temperature after sundown. The success of the first two lots of cuttings indicates that simple and inexpensive equipment will give excellent results where the climatic conditions are favorable.

The use of the solar propagating frame would be manifestly adapted to seasons of the year when sunny weather generally prevails, but is not necessarily limited to the hottest months of the year. In sunny climates, as in California and the Southwest as well as in portions of the Gulf Coast States, such a propagating bed, with slight modifications should be usable most of the year.

SUMMARY

Propagation by the use of cuttings is often desirable and may be vitally necessary to utilize successfully seedless or few-seeded species, varieties, or hybrids of citrus and other subtropical plants.

With careful control of atmospheric humidity slender twig cuttings can be utilized, retaining the leaves in active condition. Such twigs are produced in abundance and make possible the rapid building up of a large stock of plants from single individuals, thus insuring a uniformity not found in seedlings.

Bottom heat is usually a prerequisite to the attainment of a high percentage of rooted plants from cuttings. The usual method of obtaining bottom heat, that is, by the use of steam-heated greenhouses, is very satisfactory, but it is so expensive as to discourage the practice of rooting citrus cuttings on a commercial scale.

A rooting frame of simple construction which utilizes sunlight as a source of bottom heat has been found to give excellent results with the plants experimented with, including most of the standard citrus rootstocks as well as the newer hybrids.

The method is economical and offers considerable promise for other groups of plants, especially of subtropical character. The use of a solar rooting frame is obviously best adapted to the warmer sections of the country having a relatively large proportion of sunshine.

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